CCN Economics: Can ISPs Profit by Introducing CCN?

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***Abstract*—Content centric networking (CCN) has attracted a great deal of attention as a network that can efficiently deliver content. In CCN, content is delivered using the content name, instead of the host IP address, from cache memory implemented at routers. The nodes sending content are not explicitly indicated, and content is delivered from routers that have copies of content on the routes where the Interest packets are transmitted. Therefore, as a result of introducing CCN in ISP networks, the pattern of traffic exchanges among ISPs will change considerably. Customer ISPs normally pay a transit fee to transit ISPs based on the traffic volume transmitted on the transit links. Therefore, the introduction of CCN by ISPs will affect the profit of ISPs. CCN is introduced and operated by ISPs based on their business judgment, so it is important to estimate how CCN affects ISP profit in order to investigate the likelihood of CCN spreading among many ISPs. In this paper, we formalize the profit of ISPs when implementing CCN, assuming a hierarchical topology of ISPs in three levels and investigate the likelihood of CCN spreading through numerical evaluation.**

I. INTRODUCTION

A large part of traffic in the Internet is occupied by content-delivery services including web content, UGC (user generated content), e.g., YouTube, and rich content, e.g., movies and TV programs, provided by commercial content providers (CPs). A content delivery network (CDN), which improves the response time by delivering content from cache servers deployed in many networks, is widely used in content-delivery services. Although CDN providers which are independent of ISPs have been mainly provide the CDN infrastructure by deploying many cache servers in networks of many access ISPs, ISPs start to provide CDN service by themselves and make a federation among multiple ISPs operating CDNs [5]. However, in the Internet, packets are transmitted in networks using the IP address of destination hosts as the locator, so we cannot avoid the overhead of resolving the IP address of content-delivery servers from the name of the content prior to the content delivery.

Therefore, content-oriented networking (CON) has been attracting a lot of attention [7] as a means of delivering content efficiently. In CON, packets are transmitted using the content name as the routing locator, and content is dynamically cached at routers. Although various types of networking including content-centric networking (CCN) [13] and information-centric networking (ICN) [1] have been proposed based on the concept of CON, we focus on CCN in this paper. To request content in CCN, users send packets called *Interest*, and the routers transmit the Interest packets (hereafter, “Interest”) to the servers providing the original content. Cache memory is implemented at routers in order to cache content[1], and each router on the delivery route of content autonomously caches the content received. When a router receiving Interest has a copy of the content requested, the router delivers the content to the requesting user without forwarding Interest to the next-hop router. Using CCN, we can avoid the overhead of name resolution and can expect to reduce the transmission delay and the network load because content can be delivered from the location closer to users compared with delivering it from the original and cache servers.

The Internet consists of multiple networks called *autonomous systems* (*ASes*), which are operated by various autonomous organizations including ISPs, universities, and private companies. Each network maintains connectivity to all the networks constructing the Internet by paying a transit fee to the transit ISPs[2] [16]. In many cases, the transit fee is a usage-based charge corresponding to the 95 percentile of the average data bit rate in every 5-min bins [6][8][16]. When ISPs introduce CCN, the pattern of traffic exchanges among ISPs will change considerably, so the transit fee paid by customer ISPs to transit ISPs will also change. CCN is introduced and operated by ISPs based on their business judgment, so it is important to estimate the effect of CCN on the profit of ISPs in order to investigate the feasibility of CCN becoming more widespread by many ISPs.

In this paper, we formalize the amount of traffic exchanged among ISPs using CCN or CDN assuming a hierarchical topology, and we analyze the effect of introducing CCN on the profit of each ISP. In Section II, we describe the modelings used to derive the profit of ISPs and formalize the amount of inter-AS traffic among ISPs without caches, with CDN, and with CCN in Section III. We show the numerical results in Section IV, and we conclude this paper in Section V.

II. MODELINGS

In this section, we describe the modelings of content, costs, ASes, and AS policies assumed in this paper to derive the profit of ISPs using CCN.

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[1] Although content is cached in the unit of *chunks* obtained by dividing content in multiple pieces, we use the term *content* to describe the unit of data cached.

[2] In addition, there are also other types of connectivity through which networks can exchange traffic free of charge, i.e., free peering and IXPs (Internet exchange points).

A. Content Model

We assume that M rich content is provided over the networks of all ASes. For simplicity, we assume that the size of each content item is identical to L Mbytes. Let d denote the average monthly views of each user, and we assume that each content m is selected with the probability of q_m in each viewing request. Content IDs are set in the descending order of q_m, so q_1 and q_M indicate the ratio of requests for the content with the highest and lowest popularities, respectively, for example. We define $Q(m)$ as the cumulative distribution of q_m, i.e., $Q(m) = \sum_{i=1}^{m} q_i$, and let U_1 and U_2 respectively denote the total number of users and CPs accommodated by all the ASes.

B. Cost Model

1) Transit Fee: In the Internet, many transit ISPs charge the transit fee to each contracted customer ISP based on the data-transmission rate carried on the transit link. An analysis of transit charges of ISPs in 20 areas of the USA in 2004 indicated that the transit fee in one month, T (USD), is proportional to the amount of data transmitted per second, V (bps), powered by 0.75, and T can be approximated as $T = 100V^{0.75}$ [6].

Many ISPs use the 95th percentile of the data transmission rate every 5 minutes as V, and we assume that the 95th percentile of the data transmission rate is three times the average data transmission rate [8]. Packets are transmitted on each transit link in two directions: from provider to customer (denoted as *downhill direction*) and from customer to provider (denoted as *uphill direction*). There are two types of charging models for the transit fee; one uses the larger value of V in the two directions (denoted as *max model*), and the other uses the sum of V of both directions (denoted as *sum model*) [16]. Therefore, assuming that the number of days in one month is 30 days, we have

$$V = (3 \times 8LD)/(30 \times 24 \times 3600) = 1.08 \times 10^{-5}LD. \quad (1)$$

Here, D is defined by

$$D = \begin{cases} \max(D_d,\ D_u), & \textit{max model}, \\ D_d + D_u, & \textit{sum model}, \end{cases} \quad (2)$$

where D_d and D_u represent the number of content deliveries transmitted in the downhill and uphill directions, respectively. The monthly transit fee T is given by

$$T = 100 \left\{1.08 \times 10^{-5}LD\right\}^{0.75}. \quad (3)$$

2) Network Cost: To investigate the profit of ISPs, we need to consider the cost for investing in and operating the network infrastructure. In this paper, we simply assume that a fixed cost κ is incurred for each ISP in each content delivery transmitted through its network, and we apply the monthly transit fee to κ. The average transit fee per 1 Mbps in the USA in 2013 was 1.57 USD [11], and it was reported that the amount of demand at peak hours was about 1.8 times larger than the average in a commercial VoD service [18], so we give κ by

$$\kappa = (1.57 \times 1.8 \times 8L)/(30 \times 24 \times 3600) = 8.72 \times 10^{-6}L. \quad (4)$$

3) Cache Cost: When ISPs operate CCN, they need to introduce the cache memory at each router, so we also need to consider the cache memory as cost components. We assume that DRAM, which is replaced every three years, is used as the cache memory and that the DRAM cost per 1 Mbyte is 0.016 USD [15]. The cost of cache memory with a storage capacity of B in units of content is $0.016LB/36 = 4.44 \times 10^{-4}LB$ (USD).

C. AS Model

In this section, we describe the AS-level topology, the accommodation pattern of CPs and users in ASes, and the cache design assumed in this paper.

1) AS-level Topology: To formalize the flow of transit fees among ASes, we need to model the AS-level topology, i.e., the connectivity structure among ASes. We can classify the forms of connectivity between two ASes into two types: *paid peering* and *free peering*. Paid peering is often used when the scale of two ASes is largely different, and an AS with a smaller scale (called a *customer*) pays the transit fee to the other AS (called a *provider*). In other words, provider ASes such as transit ISPs provide the transit service to customer ASes. Customer ASes can assure connectivity to the rest of the world by entering into a paid peering arrangement with provider ASes. On the contrary, free peering is often used between two ASes with a similar scale, and the two ASes can exchange traffic without either of them paying a fee to the other AS.

When a paid peering contract is made between two ASes, x as *provider* and y as *customer*, the transit link connecting these two ASes is called a *provider-to-customer* (p2c) link from the viewpoint of AS x and is called a *customer-to-provider* (c2p) link from the viewpoint of AS y. Therefore, the same transit link is called a p2c link for provider AS and a c2p link for customer AS. Moreover, the link connecting two ASes with free peering is called a *peer-to-peer* (p2p) link.

In this paper, we model the AS-level topology using the following two types of data, which are publicly available in the CAIDA website [3][4].

AS Relationships Dataset [3]

All of the 85,136 links between pairs of the 18,967 ASes were classified into three types: p2p, p2c, or c2p using the method proposed by Dimitropoulos et al. [9] based on the AS topology data estimated using the BGP table from the RouteView project and routing-policy information from Internet Routing Registries (IRR) obtained in 2005.

Autonomous System Taxonomy Repository [4]

All of the 19,537 ASes were classified into six types: Large ISPs, Small ISPs, Universities, IXPs, NICs (Network Information Centers), and Customers using the method proposed by Dimitropoulos et al. [10].

17,143 ASes were included in both the data sets. Using these 17,143 ASes in the two data sets, we model the AS-level topology as a hierarchical tree topology using the following procedure.

1) Extract 17,143 ASes from the 17,826 ASes that were classified into any of the Large ISPs, Small ISPs, Universities, or Customers and were included in both data sets, excluding the three ASes having no p2c or c2p links, the 481 Customer ASes having p2c links, and the 201 ASes having c2p links with these 481 Customer ASes.
2) Extract all ASes having no c2p links among the 17,143 ASes and assign them to layer 1.
3) Among the remaining ASes, extract all ASes having one or more c2p links to any ASes classified into layer 1 in the previous step, and assign them to layer 2.
4) In the ascending order of k, repeat a similar procedure extracting all the remaining ASes with one or more c2p links to any ASes classified into layer k and assigning them to layer $k+1$, until all the 17,143 ASes are assigned into any layer.

As a result of this procedure, 17,143 ASes were classified into seven layers, and we summarize the number of ASes of each AS type in Table I.

TABLE I
NUMBER OF ASES CLASSIFIED INTO EACH LAYER IN EACH AS TYPE

Layer	Large ISPs	Small ISPs	Universities	Customers
1	10	39	0	0
2	33	2,090	189	5,123
3	1	2,574	390	4,529
4	0	668	110	1,202
5	0	60	4	106
6	0	3	0	9
7	0	2	0	1

We can regard ASes of Universities and Customers as networks accommodating users and CPs. The purpose of this paper is to analyze the transit fee, so we consider only ASes of Large ISPs and Small ISPs as the components constructing the AS-level topology, and we use the term *ISP* in the same meaning with the term *AS*. We repeated steps (2) - (4) of the above procedure for the 5,473 ASes of Large ISPs and Small ISPs, and we summarize the number of ASes classified into each layer in Table II.

TABLE II
NUMBER OF ASES CLASSIFIED INTO EACH LAYER WHEN CONSIDERING ONLY LARGE ISPS AND SMALL ISPS

Layer	Large ISPs	Small ISPs	Total
1	10	39	49
2	33	2,090	2,123
3	1	2,564	2,565
4	0	669	669
5	0	64	64
6	0	2	2
7	0	1	1

Because a large part of Large ISPs and Small ISPs was assigned to either layer 1, 2, or 3, we model the AS-level topology using the 4,737 ASes classified into the top three layers. In other words, the number of layers is $K = 3$, and N_k, the number of ASes of each layer k, is $N_1 = 49$, $N_2 = 2,123$, and $N_3 = 2,565$. Now, we define g_k^{pc} as the average number of p2c links of each AS of layer k (denoted as L_kAS) against L_{k+1}ASes. Similarly, we also define g_k^{cp} and g_k^{pp} as the average number of c2p links of each L_kAS against L_{k-1}ASes and the average number of p2p links of each L_kAS against other L_kASes. Table III summarizes g_k^{pc}, g_k^{cp}, and g_k^{pp} obtained from the connectivity structure of the 4,737 ASes.

Figure 1 shows the model of the AS-level connectivity structure assumed in this paper. We assume that each L_kAS $(1 \le k \le K-1)$ has a p2c link to each L_{k+1}AS with the uniform probability of g_k^{pc}/N_{k+1}, and each L_kAS $(2 \le k \le K)$ has a c2p link to each L_{k-1}AS with the uniform probability of g_k^{cp}/N_{k-1}[3]. Therefore, for each k of $1 \le k \le K-1$, we have $N_k g_k^{pc} = N_{k+1} g_k^{cp}$[4]. Moreover, we also assume that each L_kAS $(1 \le k \le K)$ has a p2p link with each of the other L_kASes with the uniform probability of $g_k^{pp}/(N_k - 1)$.

TABLE III
AVERAGE NUMBER OF EACH TYPE OF LINK IN EACH AS

Layer	g_k^{pc}	g_k^{cp}	g_k^{pp}
1	440.41	0.00	3.27
2	10.14	10.16	5.72
3	0.00	8.40	0.46

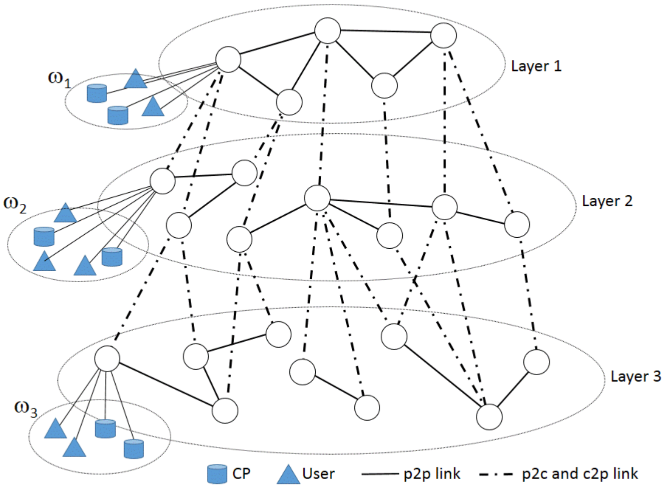

Fig. 1. Model of AS-level topology

2) Distribution of CPs and Users: Next, we describe the assumption of the allocation pattern of CPs and users among ASes. For simplicity, we assume that CPs and users are homogeneously accommodated into ASes classified into Universities or Customers in the second data set of CAIDA used in Section II-C1. The ASes of Universities and Customers assigned to layer k have c2p links against L_{k-1}ASes, so W_k, the ratio of CPs and users accommodated in L_kASes, is $W_1 = 0.460$, $W_2 = 0.426$, and $W_3 = 0.114$ as shown in Table I. Moreover, we assume that each of the N_k L_kASes homogeneously accommodates CPs and users, and that the request ratio of content of each CP, the frequency of views of each user, and the content selection probability of each user are also homogeneous. Under these assumptions, ω_k, the probability that a user requesting content and a CP holding

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[3] There are no c2p links in L_1ASes, and there are no p2c links in L_3ASes.

[4] The values shown in Table III were rounded at the second decimal place, so they are slightly different from the values obtained by this formula.

the original content is accommodated in each L$_k$AS on each content request, is given by $\omega_k = W_k/N_k$.

3) Cache Design: Because cache memory is provided at each router in CCN, the traffic demand among ASes is affected by the topology within each AS, the storage capacity of cache memory at each router, and the cache operation policy. In this paper, however, we simply assume that content is delivered from the caches of AS x if any router of AS x holds a copy of the content requested by sharing the information of cached content among routers within the network of AS x to make the analytical derivation tractable. Therefore, we do not make an explicit assumption on the storage capacity of each router or the router topology within the network of each AS, and we consider only B, the total storage capacity of all the routers of each AS, i.e., the number of content items which can be cached within each AS. Moreover, we also assume that B of all the L$_k$ASes is identical in value to B_k. It is anticipated that the scale of upper-layer ASes is larger, so we assume $B_k > B_{k+1}$ for any k of $1 \leq k \leq K-1$. When the storage capacity of caches is full, we assume that one content item is removed according to the LRU (least recently used) algorithm widely used in CDN.

III. AMOUNT OF INTER-AS TRAFFIC

A. Case of No Cache Network

First, we derive the amount of inter-AS traffic in an NCN (no cache network) in which all the content is delivered from the original servers without using any cache. Let us consider the case in which a user accommodated in an L$_r$AS requests content whose original server is accommodated in an L$_s$AS. According to the valley-free routing[12], the data packets that depart from the original server arrive at AS u_1 in layer 1 after going through only a single AS u_k at each layer k of $1 \leq k \leq s$ using just c2p links as shown in Fig. 2(a). Next, the data packets are transmitted to L$_1$AS d_1 from AS u_1[5] using p2p links. Finally, the data packets arrive at the terminal of the user who requested the content after going through only a single AS d_k at each layer k of $1 \leq k \leq r$ using just p2c links.

However, when AS u_t has a peering link with AS d_t at any layer t of $1 \leq t \leq \min(r,s)$, and AS u_k does not have a peering link with AS d_k at any of the layers k in the range $t+1 \leq t \leq \min(r,s)$, the highest layer on which the data packets travel is t. Figure 2(a) and (b) shows examples of the route of the content-delivery flow with $t=1$ and $t=2$, respectively, when $r=2$ and $s=3$. Therefore, we have $G_{r,s,t}$, the probability that the highest layer of the delivery route is t, as

$$G_{r,s,t} = \prod_{i=t+1}^{\min(r,s)} \left(1 - \frac{g_i^{pp}+1}{N_i}\right) \frac{g_t^{pp}+1}{N_t} \tag{5}$$

for each t of $1 \leq t \leq \min(r,s)$, and $G_{r,s,t} = 0$ for each t of $\min(r,s) < t \leq K$. Hence, for the given r and s, we obtain $\phi_{r,s,k}$, the probability that a delivered flow of content takes each c2p link of each L$_k$AS in the uphill direction, as

$$\phi_{r,s,k} = \sum_{t=1}^{k-1} \frac{G_{r,s,t}}{N_k g_k^{cp}} \tag{6}$$

when $k \leq s$, and $\phi_{r,s,k} = 0$ when $k > s$. Similarly, the probability that the delivery flow goes through each c2p link of each L$_k$AS in the downhill direction is also given by $\phi_{s,r,k}$ because we assume that CPs and users are accommodated uniformly as mentioned in Section II-C2. Moreover, the probability that the requesting user or the original server exists in the customer cone of an L$_k$AS is $1/N_k$, so $\mu_{r,s,k}$, the probability that the delivery flow goes into the network of each L$_k$AS through each p2p link or from its accommodating CP, is given by

$$\mu_{r,s,k} = \frac{G_{r,s,k}}{N_k(g_k^{pp}+1)}. \tag{7}$$

Let $F_{u,k}$ and $F_{d,k}$ denote the probability that a delivery flow takes each c2p link of each L$_k$AS in the uphill and downhill direction, respectively. Moreover, we also define $F_{p,k}$ as the probability that a delivery flow goes into the network of each L$_k$AS from peer ASes or its accommodating CP. We have

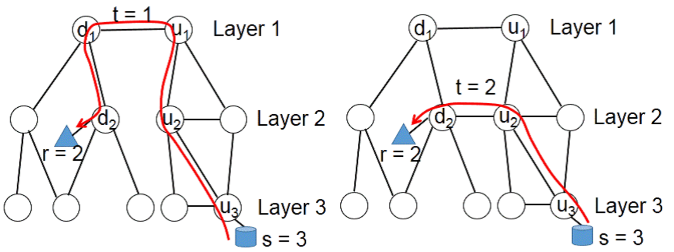
$$F_{u,k} = F_{d,k} = \sum_{r=1}^{K}\sum_{s=1}^{K} \phi_{r,s,k} W_r W_s, \tag{8}$$

$$F_{p,k} = \sum_{r=1}^{K}\sum_{s=1}^{K} \mu_{r,s,k} W_r W_s, \tag{9}$$

and obtain H_k, the probability that a delivery flow goes into the network of each L$_k$AS is

$$H_k = g_k^{pc} F_{u,k+1} + g_k^{cp} F_{d,k} + (g_k^{pp}+1) F_{p,k}, \tag{10}$$

where $F_{u,K+1} = 0$.



(a) Case of t =1 (b) Case of t =2

Fig. 2. Example routes of content-delivery flow

B. Case of CDN

Next, we consider the case that all ASes contract with CDN providers, and each L$_k$AS connects with cache servers with the total storage capacity of B_k. For simplicity, we do not consider the federated CDN among multiple ISPs. When a user accommodated in L$_k$AS x requests content m, it is delivered from the cache server of AS x if there exists a copy of content m in any cache servers of AS x, i.e., in the case of *cache hit*, or content m is delivered from the original server if no cache servers of AS x keeps content m, i.e., in the case of *cache miss* [17]. Therefore, the cache servers of AS x are

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[5] When the inter-AS route turns back on the single AS at layer 1, d_1 agrees with u_1.

used only for the users accommodated by AS x. L$_k$AS x does not cache content whose original servers connect with AS x, and the ratio of users accommodated in AS x is ω_k, so the probability that each content becomes the cache target in AS x is $1-\omega_k$. Popular content is more likely to be cached because the content accessed the least recently is removed according to the LRU cache-replacement algorithm, so we assume that the most popular $B_k/(1-\omega_k)$ content exists in the cache servers of L$_k$AS x.

By defining ρ_k, the effective cache capacity of each L$_k$AS, as $\rho_k = \min\{B_k/(1-\omega_k),\ M\}$, we can say that content m of $1 \le m \le \rho_k$ is delivered from the cache servers for the users accommodated in L$_k$ASes. Therefore, the probability that content is delivered from the original server is $1 - Q(\rho_k)$, and we obtain

$$F_{u,k} = F_{d,k} = \sum_{r=1}^{K}\sum_{s=1}^{K}\phi_{r,s,k}W_rW_s\{1-Q(\rho_r)\}, \quad (11)$$

$$F_{p,k} = \sum_{r=1}^{K}\sum_{s=1}^{K}\mu_{r,s,k}W_rW_s\{1-Q(\rho_r)\}. \quad (12)$$

H_k is also given by (10).

C. Case of CCN

Finally, let us consider the case in which all the ASes introduce CCN. With g_k^{pp} peering ASes, L$_k$AS x shares the routing information of the content whose original servers are accommodated into AS x or ASes of its customer cone. Hence, AS x can avoid duplicate caching of the same content among these $g_k^{pp}+1$ ASes including itself. Therefore, the probability that each content item is the caching target of each L$_k$AS is given by $\{1-\omega_k(g_k^{pp}+1)\}/(g_k^{pp}+1) = 1/(g_k^{pp}+1) - \omega_k$, and when the effective cache capacity σ_k is defined as

$$\sigma_k = \min\left\{\frac{B_k}{\frac{1}{g_k^{pp}+1}-\omega_k},\ M\right\}, \quad (13)$$

we can say that content m in the range of $1 \le m \le \sigma_k$ is cached in each L$_k$AS.

Now, we consider the case in which the Interest for content whose original server is accommodated into an L$_s$AS is generated from a user accommodated in an L$_r$AS, and the highest layer through which the Interest takes is t. In this case, the delivery flow of content goes through the c2p link of L$_k$AS x in the uphill direction only when the Interest generated from a user not belonging to the customer cone of AS x reaches AS x via each AS of layer $r,\ r-1,\ \cdots,\ t,\ t+1,\ \cdots,\ k-1$. Figure 3(a) shows examples of routes of the Interest and content when the delivery flow of content takes the c2p link of AS x in the uphill direction in the case of $r=3$, $s=3$, and $t=1$. The Interest reaches AS x only when the requested content is not cached at all of AS a, AS b, AS c, or AS d. As mentioned in Section II-C3, we assume $B_i < B_j$ when $i < j$, so the maximum value of σ_k of ASes on the route of the Interest is σ_t, and content m of $1 \le m \le \sigma_t$ does not reach AS x.

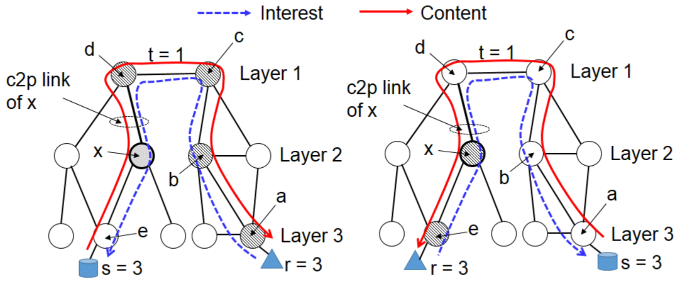
On the other hand, the delivery flow of content goes through the c2p link of L$_k$AS x in the downhill direction only when the Interest generated from a user belonging to the customer cone of AS x reaches L$_{k-1}$AS d, which is the provider AS of AS x via each AS of layer $r,\ r-1,\ \cdots,\ k+1$ as well as AS x. Therefore, in the example shown in Fig. 3(b), the Interest reaches AS d only when content is not cached at either AS e or AS x, so content m of $1 \le m \le \sigma_k$ does not reach L$_{k-1}$ASes. Moreover, the delivery flow of content goes into the network of AS x from peering ASes only when the content requested is not cached at each AS in layer $r,\ r-1,\ \cdots,\ k+1$ on the route of the Interest, so only content m of $m > \sigma_{k+1}$ comes from peering ASes. Therefore, we have

$$F_{u,k} = \sum_{r=1}^{K}\sum_{s=k}^{K}\sum_{t=1}^{k-1}G_{r,s,t}\frac{W_rW_s}{N_k g_k^{pc}}\{1-Q(\sigma_t)\}, \quad (14)$$

$$F_{d,k} = \sum_{r=1}^{K}\sum_{s=1}^{K}\phi_{r,s,k}W_rW_s\{1-Q(\sigma_k)\}, \quad (15)$$

$$F_{p,k} = \sum_{r=1}^{K}\sum_{s=1}^{K}\mu_{r,s,k}W_rW_s\{1-Q(\sigma_{k+1})\}. \quad (16)$$

H_k is also obtained by (10).



(a) (b)

Fig. 3. Example routes of Interest and content deliveries in CCN

IV. NUMERICAL EVALUATION

In this section, we show some numerical results using the formulae derived in Section III.

A. Evaluation Conditions

We set the monthly access charge for each user as $P_r = 50$ USD, and we set the total number of users and CPs as $U_1 = 10^9$ and $U_2 = 10^4$, respectively. We also set the average number of requests generated from each user within one month as $d = 10$ and the average content size as $L = 3 \times 10^4$ Mbytes [14]. The total amount of content, M is set to 10^6, and we assumed that the ratio of requests for content m obeys the Zipf distribution with parameter θ, i.e., $q_m = (m^\theta \sum_{j=1}^{M} 1/j^\theta)^{-1}$. Moreover, using a given value of B_K, the cache capacity of the lowest-layer AS, i.e., L$_K$AS, and a parameter ϵ taking a real number greater than unity, we set $B_k = \epsilon B_{k+1}$ for each k of $1 \le k < K$. In the following evaluations, we set $\theta = 1$, $B_K = 10$, and $\epsilon = 5$ unless otherwise stated.

B. Profit of ISP

Figure 4 plots R_k, the monthly profit of each L$_k$AS against θ or B_K for each of the three methods, NCN, CDN, and CCN, when using the *max model* and the *sum model* for the transit fee. The transit fee using the *sum model* was larger than that using the *max model*, so the profit of the L$_1$ASes was larger, whereas the respective profits of the L$_2$ASes and L$_3$ASes were smaller when using the *sum model* compared with using the *max model*. Introducing CCN was effective to reduce the network cost even for L$_1$ASes. However, the decrease in the transit fee obtained from L$_2$ASes was larger than the decrease in the network cost when using the *sum model*, so the profit of L$_1$ ASes with CCN was smaller than that with CDN under the *sum model*.

$F_{d,2}$, the probability that a content-delivery flow takes each c2p link of each L$_2$AS in the downhill direction, was larger than $F_{u,k}$, that in the uphill direction, so the transit fee was determined by $F_{d,k}$ in the *max model*. Therefore, the decrease in the transit fee obtained from L$_2$ASes was not remarkable, and R_1 of CCN was close to that of CDN in the *max model* because the decrease in the transit fee was offset by the reduction of the network cost. As θ or B_K increased, and the effect of the caches increased, the profit of the L$_1$ASes decreased because the decrease in the income obtained from the transit fee exceeded the reduction of the network cost for the L$_1$ASes. In contrast, for the L$_2$ASes and L$_3$ASes, both the transit cost and the network cost were reduced, so their profit increased.

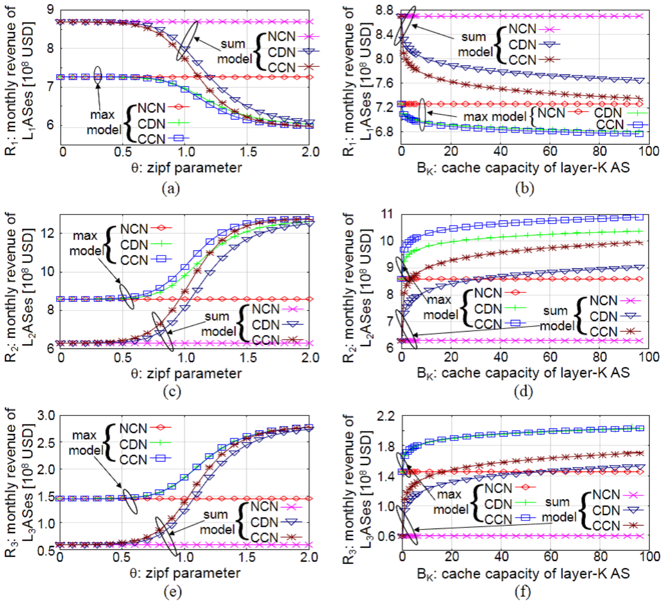


Fig. 4. Monthly revenue of each AS

V. CONCLUSION

Although CCN has attracted a great deal of attention as a new network architecture for efficiently delivering content, the effect of introducing CCN on the profit of ISPs had not yet been investigated. In this paper, we modeled the inter-AS topology using a hierarchical three-layer structure and derived the profit of ISPs when using no caches (NCN), using CDN, and using CCN. We summarize the main findings obtained through the numerical evaluation as follows.

- The profit of ASes in layers 2 (L$_2$ASes) and 3 (L$_3$ASes) increased by introducing CCN because both their transit cost and network cost were reduced. The benefit to these ASes of using CCN was more remarkable as the cache capacity or the bias of content popularity increased.
- The profit of L$_1$ASes was not strongly affected by the introduction of CCN when using the *max model* as the transit fee, whereas the profit of L$_2$ASes decreased by introducing CCN when the *sum model* was used as the transit fee. Therefore, there was no advantage for L$_1$ASes in introducing CCN. We need to introduce a mechanism that gives an incentive to L$_1$ASes to expand the use of CCN, for example, a mechanism letting L$_2$ASes pay a fee to L$_1$ASes in compensation for the profit decrease of the L$_1$ASes.

Because CCN is introduced by ISPs based on their selfish decisions, only some ISPs introduce CCN, and the other ISPs continue to use CDN in the process of spreading CCN among ISPs. Therefore, we will analyze the profit of ISPs when only a portion of ISPs introduce CCN. We will also investigate various methods of giving an incentive to L$_1$ASes to introduce CCN in future.

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